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A REPORT OF A CONFERENCE ON

ADVANCED COMPOSITES --- AN ASSESSMENT OF THE FUTURE

June 10-11, 1975

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A REPORT OF A CONFERENCE ON ADVANCED COMPOSITES -- AN ASSESSMENT OF THE FUTURE

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THE CONFERENCE -- IN SUMMARY

The conference was held to evaluate the current status and future commitment to composites by government and industry. This reassessment, the first since Project RECAST in 1972, was felt needed because of an apparent transition in the acceptance of composites. Whereas composite applications prior to 1972 were largely of the material replacement category, aircraft are beginning to have composite secondary structural components in their baseline design. Yet, their extensive acceptance for secondary structure and their growth to primary structure appeared to be reaching new obstacles. Thus, it was opportune to have the management of government agencies restate their progress and commitment to the development of composites and to have industrial management define their concerns and requirements to commit to the future use of composites.

The most significant result of the RECAST study of 1972 was that the barriers to increased utilization of composites were confidence and cost. As a consequence, government programs since that time have emphasized substitution type flight demonstrations of composite aircraft

components and the development of manufacturing methods to reduce delivered cost.

The results of the 1975 assessment again identified confidence and cost as the major factors inhibiting the future use of composites. Currently, however, confidence exists in applications to secondary structure, whereas additional demonstration programs of primary structure are still required, including their continued operation in the service environment. The reemphasis on cost includes not only the cost of a delivered component, but also a verification of assumed manufacturing learning curves, certification costs, and maintenance costs during the lifetime of the vehicle.

THE AGENCY VIEWPOINTS

One characteristic of the agency statements was the consistent assurance of the potential performance benefit of advanced composites. Virtually regardless of the application, each agency readily identified composite components which resulted in weight reductions of from 15 to 50%. To utilize a composite material in the final item or component it must be proven to be cost effective. The value of weight saved depends on the application, varying from 6 cents per pound for simple bridges to \$50 to \$200 per pound for aircraft to \$1000 or more per pound for space vehicles.

The summaries which follow emphasize the assessment and commitment to the major applications of each agency. Each agency stated a parallel commitment to increase the predictability of the performance of composite structure.

ARMY STATUS AND COMMITMENT

Army applications include the complete spectrum of systems from aircraft and missiles to ground vehicles and civil engineering systems. Some of the current Army component programs intended to demonstrate the usefulness of advanced composite materials are listed in Figure 1.

The application of advanced composites to new designs has been conservative and cautious because of the lack of confidence in cost and long-term durability. The Advanced Development Programs listed in the first figure will evaluate structural concepts using advanced composites in a more liberal manner to explore their full potential.

In addition to the Advanced Development Program, the Advanced Structures Technology Demonstrator (ASTD), shown in Figure 2, will make maximum use of advanced composites in its baseline design and provide a test bed for component structural test and service evaluation. The ASTD aircraft is intended to overcome the limitations of replacement components and demonstrate the synergistic effect of advanced composites on the reduction of structural weight fractions, design gross weight, and installed horsepower.

A preliminary design study is nearing completion to develop structural concepts for a medium-range utility helicopter prototype.

The culmination of the advanced composite design, fabrication and test programs is the installation of components on aircraft for flight evaluation. The Army plans for component and prototype flight is included in Figure 1.

Perhaps the most radical departure from conventional military operations in the past two decades has been the growing trend toward air mobility, with the resultant tactical reliance on the helicopter. Implicit in this trend is the need for lightweight, cost-effective, reliable helicopters and the field equipment and material to be carried by them. Thus, a much greater use of advanced composite materials will be made for applications, such as those listed in Figure 3.

For cost benefits reasons, most of the current applications for advanced composites have been to meet aerospace requirements, and most of the Army applications have been for helicopters. This is reflected in the current status and future plans for the use of composite materials in Army helicopters as shown in Figure 4.

The principal Army effort in the area of designer/user confidence has been the deterioration program. The objec-

tive of this program is to predict and prevent chemical and mechanical deterioration in fiber-reinforced composites. The concept is to take well-characterized composite materials and measure their properties before, during, and after environmental exposure. Another area of investigation requiring user confidence is that of composite material damage tolerance. In an experimental evaluation, it was shown that hybrid composites containing Kevlar and graphite are superior in damage tolerance to metal components -- and save weight.

The major emphasis for cost reduction in advance composite materials is the manufacturing technology discipline. Some of the Army's recent efforts include automated tape layup and filament winding of large, complex sections of helicopter structure; a machine designed to utilize composite broadgoods for the layup of wide parts or complex components with ribs and stiffeners; the use of low-cost Hot Layup Tooling (HLT) to fabricate complex composite structural components; the microwave curing of thick composite sections, such as rotor blade root ends and tank armor applications (cure time reduced from 16-20 hours to 2 hours); and the Pultrusion process for the forming of composite reinforced constant cross-section channels or shapes.

Recent developments in graphite reinforced aluminum matrix composites makes this material attractive for Army

applications. Based on the utilization of a low-cost graphite fiber ($5-$10 per pound) and the development of a continuous wire/tape production process, the future cost of Gr/Al composites is predicted to be competitive.

Several Army Gr/Al composite development and manufacturing technology programs are under way or planned, including the construction of a Gr/Al wire production facility and the fabrication of crown frames and transmission housing stiffeners for the CH-47 helicopter.

Future Army program efforts will be directed toward both resin matrix and metal matrix composites development and application for aircraft, as well as missiles, surface vehicles, bridging components, protective equipment and weaponry.

NAVY STATUS AND COMMITMENT

The Navy involvement in advanced composite development began in the early 1960's with the evaluation of composite materials and feasibility demonstrations. By 1970 this technology base began feeding into programs concerned with small aircraft component development. Several of these components, which are currently under construction and evaluation, are listed in Figure 5. These applications offer a potential weight savings ranging from 8% to 54% and a cost reduction of 17% to 30%. Valuable information for future aircraft designs will be obtained in the areas

of component reproducibility, production quality control, cost, operational durability, maintenance experience, repair techniques, redesign recommendations and problem identification. The Navy is also evaluating battle damage tolerance and containment design concepts, including full-scale component testing.

The data and experience gained under these programs are currently providing the basis for the large primary structure component designs shown in Figure 6. These designs make extensive use of Graphite/Epoxy (Gr/E) composites in secondary and primary structure.

Advanced composite feasibility is firmly established. The present question is their practicality, acceptability and extent of use. Composites technology must now rely on limited service data, soft or questionable cost estimates, metal backup designs, long development lead time, and a variable industrial state-of-the-art. Near term production applications are the key to advanced composites maturity. The critical technical/confidence factors are: (1) adequate design and fabrication technology, (2) long-term service durability, and (3) greater credibility in production and life cycle costs.

The current Navy commitment to Gr/E advanced composites for airframe applications is characterized by selected components of secondary structure, full depth honeycomb

primary structure and flight critical primary structure where accessability, metal fall-back, cost and schedule are satisfactory. Advanced design Navy aircraft being considered for advanced composites include the F-18, Advanced Harrier and V/STOL concepts. The current F-18 design includes Gr/E in about 13% of the structural weight. More extensive use of these composites is expected in the V/STOL type aircraft due to the increased propulsion weight which places a premium on airframe weight reduction, as shown dramatically in Figure 7.

Extensive use of composites in future Navy systems is dependent on a data base of mechanical properties, environmental effects, fabrication characteristics and functional factors. Navy composite evaluation programs will emphasize the areas identified in Figure 8, particularly as they relate to the marine environment.

Other composite systems under investigation for specific applications include: (1) B/Ti Composites for VTOL hot gas exposures; (2) Polyimide resin matrix for high temperatures; (3) Reinforced thermoplastics for low cost formed sheet; and (4) Polyurethane protective coatings for resin matrix composites. Characterization is of particular importance in quality control and emphasis will be placed on the evaluation of detection techniques to identify and control the molecular structures concerned.

The objective of the Navy data generation programs is to establish a sufficient data base for the acceptance of composites in future designs -- with confidence in their performance and durability.

AIR FORCE STATUS AND COMMITMENT

The Air Force emphasis on confidence and cost includes materials/manufacturing processes, component demonstrations, service experience, life assurance, and conceptual design studies. A variety of aircraft structural components are being designed, fabricated and evaluated, as shown in Figure 9, to gain experience for production and flight demonstration. Other, more recent, component fabrication programs include the B-1 horizontal stabilizer, F-15 speed brake, F-111 horizontal stabilizer and Advanced Development Program torque box covers.

The Air Force in-service evaluations, listed in Figure 10, have greatly increased confidence in the operational use of advanced composites. Some performance difficulties have been uncovered, such as thin skin damage, moisture incursion, hole deformation, disbonds and maintenance damage. Corrections have been relatively straightforward through design and fabrication modifications. Evidence indicates that the ability to repair is excellent, but criteria on when to repair are lacking.

Another potential use of advanced composites is engine components, such as fan blades, stator vanes, compressor blades and frame sections. In these applications, both weight and cost reduction are important and will be exploited. As shown in Figure 11, composites in current military engines make possible a 30-40% component weight and cost reduction.

The "first generation" of Air Force advance composite structures were designed on a material substitution basis. The "second generation" of designing for composites during the conceptual stage has been initiated in the Light Weight Fighter forward fuselage program and the B-1 empennage and secondary structure programs.

A major cost reduction program includes the development of new or improved materials and manufacturing methods. These "major thrusts" in component cost reduction are indicated in Figure 12. In particular, graphite reinforcement could be obtainable at $7-8/lb. in the near future if sufficient volume production could be achieved through commercial applications.

An item of growing interest to all is the amount of energy required to produce aircraft components. Advanced composites offer significant energy savings. For F-15 wing skins, advanced composites offer a 6-fold reduction in

energy compared to aluminum and a 45-fold reduction compared to titanium.

It is clear that the development of advanced filamentary composites has progressed well beyond a materials technology into a structural and air vehicle system technology. As indicated in Figure 13, during the past five years, a stable material base and the ability to design stiffness critical structures has emerged and several such components have gone into production.

During the next five years, the ability will be developed further to apply composite materials to larger, strength critical structures. Existing applications will continue to evolve in aircraft, engines, missiles, and spacecraft. Composite structures will come into actual cost parity and begin to show as much as 15% cost saving.

Beyond the early 1980's the opportunity for a substantial, volume production of composite structures will be apparent. Designs for advanced air vehicles built predominantly from composite materials will develop with a significant departure from today's vehicle designs and production approaches. In this period, the airframe use of composites will grow from the current 5-10% to 40-65%.

In the near term, the factors to be addressed must include structural certification strategy, detailed design of strength critical structure, low cost manufacturing,

materials, and aeroelastic tailoring. At present, either composite structure must be overdesigned or each article must be proof loaded to meet the requirements of the Aircraft Structural Integrity Program and Mil Spec 1530. Life assurance technology must be available before the general use of composite materials in airframe structures can become a reality.

The Air Force management options for composite structure are shown in the very preliminary roadmap of Figure 14. The pacing technology in the midterm is the conversion of the composite materials/structures potential into an advanced systems potential. This could be accomplished either by a step by step evolution through a component modification program or by experimental demonstration through demonstrator/prototype aircraft. The empennage, wing, and fuselage replacement components for the B-1 and F-16 aircraft will be available in 1978 or 79. The study and preliminary design activities to support an advanced design composite aircraft would also be definitive by that time. A decision must then be made either to continue the step by step processes or move toward a complete demonstrator vehicle. The fuselage components are a continuing development for existing aircraft, whereas the integration demonstrator leads to the prototype/production opportunity.

The projected Air Force economic commitment to continue the development and transition of composite technology into system applications is shown in Figure 15. Exploratory Development funds will be used for the technology base and new technology leads, such as a moisture resistant resin, a fracture arrest mechanism, a new analysis technique, etc. A substantially increased program is planned to develop new or improved, low cost manufacturing techniques. Advanced Development includes the Air Force's structural demonstration programs, the life assurance programs, and the systems integration activities.

In summary, while progress has been substantial during the first half of this decade, continued development effort will be required throughout the rest of this decade. It can be projected, at current investment rates, that a mature advanced composite structures technology will exist in the mid-eighties to which the Air Force could confidently commit a complete composite airframe to a production aircraft program.

NASA STATUS AND COMMITMENT

The NASA advanced composites program, summarized in Figure 16, has emphasized confidence building through an on-going base technology activity, design and cost studies, and hardware applications. The broad application goals emphasize commercial aircraft, but also include military

aircraft, helicopters, aircraft engines, and space transportation systems and payloads.

As shown in Figure 17, a number of advanced composite applications have been made or are under study for a variety of space vehicles. Particularly important is the production use of several composite materials on the Space Shuttle. Safety and reliability were factors in the selection of composite overwrapped tanks because of their nondestructive failure mode. The specialized use of low coefficient of expansion composites is particularly well suited to space structures, such as telescopes, which require precise dimensional stability.

NASA has initiated a comprehensive program to improve the impact resistance of advanced composite blades through the use of fiber hybridization and improved resin materials, and a more ductile metal and larger diameter fibers in metal matrix composites. The improvement in impact resistance for a large resin matrix blade is shown in Figure 18. An interdependent Air Force/NASA program is directed toward meeting the FOD requirements of B/Al composite blades for the J-79 engine.

A significant effort is being devoted to determining the effects of long-term environmental exposure on the properties of composite materials for airframe applications. Stressed and unstressed samples are being exposed world wide

at several airports. Laboratory simulation of ambient and altitude pressures/temperatures and outdoor exposure up to 50,000 hours, followed by testing of exposed specimens is presently underway on numerous t pes of advanced composites.

The NASA flight service programs, summarized in Figure 19, are conducted to obtain experience in the design, manufacturing, and operational performance of a variety of aircraft components. The primary focus for the flight programs is commercial aircraft which allow the accumulation of about 3000 hours per year of flight time.

The complexity of the demonstration components has increased from the early fairings, through progressively more complicated secondary structure, to the recently initiated L-1011 vertical tail program, shown in Figure 20. Each of the commercial aircraft flight articles is FAA certified and flown by several scheduled airlines. A total of over 2.5 million flight hours will be logged on these components by 1982.

NASA's future advanced composite programs are primarily aimed at two applications. The first is a continuation of programs to demonstrate low cost and long life and to gain maintenance and repair experience for applications to civil aircraft and engines. The second supports the wide variety

of devices used to go into, operate in, and explore and exploit space.

A future commercial transport might consist of a composite vertical tail and horizontal stabilizer, composite fuselage, composite nacelles, and a composite wing -- in other words, virtually the entire airframe could be of advanced composites. Recent progress in producing FOD resistant, advanced composite fan blades has convinced NASA that the required toughness can be achieved. Thus, a large portion of the cold end of the engine might contain composites. At some later time, high temperature composites, such as eutectics and fiber reinforced superalloys, could be used in the turbine (hot) end of the engine.

The payload of future space shuttles could be increased by the incorporation of additional advanced composite components. Further in the future, a much greater payload, second generation space transportation system might have a higher temperature, advanced composite primary structure, control surfaces, and tanks.

NASA has a firm commitment to continue the advanced composites, base technology program and an equally firm commitment to conduct those demonstrations needed to assure user confidence in performance and to verify predictions of low initial and operational cost.

A major program currently being planned is the design, fabrication, ground test, and flight service demonstration of an advanced composite wing, as shown in Figure 21. Flight service will be demonstrated on a commercial transport with a wing span of 80 to 100 feet and a target weight savings of 25%.

In addition to the composite wing, a program is being planned to apply advanced composites to a sizable section of a civil aircraft fuselage. The program is in its early planning stage and would follow the wing. The initial concept is to design, fabricate, ground test, and perhaps fly a fuselage section some twelve feet in diameter by about twenty-five feet long.

NASA will continue to pursue its interest in applying advanced composites to the cold end of the engine --- with most of this interest concentrated on fan blades. Future programs would include fan blades, fan frame, and the containment ring. The program would provide design, component development and ground tests, including those to demonstrate resistance to foreign object damage.

The application of composites to the current space Shuttle has already been mentioned. The goal of a recently initiated program is to develop materials and manufacturing methods for composites to operate up to 600°F, and to fabricate and test full size structural components. The

program has been designed so that the option is retained to demonstrate performance on a Shuttle vehicle at some later date.

Figure 22 is a financial summary of the NASA on-going and future programs. These programs constitute the continuing NASA commitment to the development of composites.

NASA has a strong conviction that composites will make a significant contribution to the nation's future and is firmly committed to a growing and aggressive program to demonstrate the technological readiness of advanced composites for spacecraft and commercial aircraft and engines.

COMPOSITES -- THE NATURE OF INDUSTRIAL COMMITMENT A ROUNDTABLE

The roundtable discussion might best be characterized by a mood of cautious optimism. It was clear that the deterring factors to the acceptance of composites was confidence in the lifetime behavior of the materials and in their initial and life cycle cost. The ultimate user of the vehicle system, be it military or commercial, must have the assurance that the product will perform as designed and that there will be no surprises in terms of maintenance and operational cost.

AIRCRAFT MANUFACTURERS

During the past ten to fifteen years, the aerospace industry's interest in applying composites has basically

remained the same, a desire for more efficient airframe structure. But the promise of composites is yet to be fulfilled. An insufficient understanding of composite performance is reflected in the feeling of high risk relative to the current standard of metallic structures.

Neither the government nor industry appears confident enough to proceed aggressively to full scale use of composites in military aircraft. Overselling their use results in a belief that the success of composites will only be achieved through 100% usage for structural components. This overselling is closely allied to the government process for obtaining funds which allows for successes only, both in technology and in major weapon system developments. A number of composites technology programs have experienced characteristic start and false start, as well as stop and go, syndromes. Recent military aircraft programs indicate that there has been a lack of high level government and vehicle program SPO confidence in the application of composites to important vehicle system programs.

The tendency for government interlaboratory competition for responsibilities and goals has appeared to delay progress in some development programs. Industry has a parallel difficulty in the internal conflicts between experience material designers and the new composite design specialists.

The manufacturer repeatedly has heard over optimistic projections of material costs, which never seem to reduce as rapidly as the annual projected forecasts indicate. Furthermore, nonuniformity of batches of materials seems to be the norm on most composite programs. The limited, small statistical samples of materials and components on which future behavior must be predicted is not confidence inspiring. On these bases, cost tradeoffs are still marginal, the reliability of the cost data are questionable, and cost benefit ratios need to be more clearly understood and defined.

On the positive side, the rapid progress of composites in the last 10 to 15 years compares favorably with that of metallic materials introduced in the past. The deliberate, simultaneous development of materials, design, analysis, and manufacturing technologies is one factor in this rapid development. The early recognition and achievement of competitive materials sources is indicative of the simultaneous development.

Systems design studies and composite component development and test programs have satisfied the initial goal of demonstrating potential weight savings on a substitution design basis. These design studies led to the early development of production applications, such as those on the F-14 and F-15 aircraft. Finally, the evolution of

basic technologies at user facilities, rather than exclusively at universities and government laboratories, will aid in their early use.

The inherent advantages of composites in weight, stiffness, and strength, together with their potential cost saving and increased service life, make them most attractive for almost every type of future military aircraft application. With sufficient confidence in the technical and economic aspects of composite application to production components, extensive use will occur on future military aircraft.

In commercial transport aircraft, advanced composites in secondary structures will be the basis for an evolutionary increase in secondary structure applications, provided they are cost effective. This cost effectiveness will have to cover, of course, both the initial cost and maintenance or cost of ownership. However, no one at this time has the confidence or the background to commit to their use in primary structure. Wings now cost on the order of $40 per pound and any new material must be competitive in terms of total life cycle costs.

The current trend in court judgements on the broad subject of product liability is of increasing concern to anyone considering the use of advanced technology. Any new material must have the same high degree of safety and

reliability as that which is being replaced. The current NASA Programs have been insufficient in scope to get the needed experience. Obviously, the FAA and the airlines must be deeply involved in such programs.

The general aviation manufacturers have been following the development of composites for potential application. The greatest deterrent to use is cost. Graphite, which has looked best, is far more expensive per pound than aluminum. In addition to the basic material cost problem, reliable manufacturing methods must be able to produce parts which are cost competitive in the less expensive, general aviation aircraft.

Lack of experience or confidence is another problem. It took many years to develop the skills for designing and building safe general aviation airframe structures from metals. Although these new materials are attractive in many ways, there is little hope for extensive use until lower cost and better confidence exist.

AIRCRAFT ENGINES

Presently, 2-5% of the weight of current engines is composites. Projections for the use of composites in engine structures and rotating parts indicate a weight savings of 30-35% and a concurrent cost reduction of 20-25%.

The primary fan blade problem continues to be the sensitivity of composites to foreign object damage (FOD).

Headway is being made toward a solution to this problem, but it is still a long way off. Solution of this problem is an absolute requirement before composite materials will be used in rotating engine parts. Both the weight and performance benefits possible with composite fan blades, however, warrant solving the FOD problem.

In summary, progress to date has been slow, but satisfactory. The continued development of composite blades, frames and containment should ultimately be combined in a composite demonstrator engine program. The demonstrator would be thoroughly ground tested and certified, followed by experimental flight testing, and flight acceptance for in-service demonstration.

AIRLINES

Because of the present economic situation, the Air Transportation Industry will not be able to absorb the economic disappointments of new technology in the future as they did in the past. Therefore, homework must be done more thoroughly in the future before the introduction of new and even more expensive technologies will be accepted.

A new structural technology must not contain any maintenance and reliability surprises. Quick, field repair without the need for exotic equipment is a major requirement. Aircraft out of service time, due to the kinds of structural damage presently experienced, must not be increased because of composites.

The NASA proposed composite wing and fuselage programs are commendable and should be supported with the proper funding to see them through completion. This includes a flight test program in a simulated airline operation to gain the knowledge concerning time, cycles, and environmental effects on composite structures.

The confidence level in all aspects of this new structural technology must be high before committing it to use. Greater involvement of FAA in composite demonstration programs must be assured, because FAA certification is a must to the airlines.

SPACECRAFT

The largest, near term use of composites in spacecraft will be in Space Shuttle orbiters. The orbiter now utilizes about 5,000 pounds of composite structure.

Other uses for composites on the Shuttle are being considered, as well as their use on other spacecraft. The shuttle and other spacecraft are unique in that the cost for putting a pound into orbit is far greater than the costs experienced in the fabrication of composite structure and the number of operational cycles is orders of magnitude less than aircraft.

Future technical development should be channeled to develop composites for higher temperatures, more efficient

and reliable design and fabrication techniques, a broader base for new woven forms of graphite, and the improved toughness of materials.

MATERIALS SUPPLIERS

Considerable research and development work has been done by the DOD, NASA, private industry and universities to gain the required understanding of composite materials. Currently, the user is concerned with moisture effects (particularly at high temperature), impact resistance, and the nonductible properties of composite, but these problems are not insurmountable.

The cost of a finished product is a major consideration in materials selection. Although the composite raw materials costs are high, the fabrication and assembly costs are usually lower, so that the overall cost is lower for typical applications. In addition, the price of graphite fiber is dropping and will continue to go down as the volume increases. The following table shows the probable trend.

FIBER PRODUCTION VOLUME (lb/yr)	FIBER COST ($/lb)
20,000	150
50,000	75
100,000	50
1,000,000	25
2,000,000	20

ROUNDTABLE SUMMARY

The rapid progress in the development of composites as a class of materials and the rapidity of their maturation were observed on numerous occasions. In the long term, the panel envisioned extensive use of composites with an evolutionary increase from their current limited use in secondary structure. Economic conditions are such that the near term risk to extensive use of composites cannot be justified in the current aerospace marketplace.

Continued technology efforts must address each of the issues discussed by the panel; however, the following factors are key to expanded use:

1. The effect of long term environmental factors on the performance of composite structures must be understood.

2. The cost of composite materials/structures must be realistically forecast and reduced.

3. More emphasis should be placed on the development of manufacturing methods as well as life cycle maintainability and reliability.

4. New demonstration components incorporating major composite applications should lead to a larger statistical production and flight sample.

FIGURE 1. ARMY ADVANCED COMPOSITE APPLICATIONS

COMPONENT	ADVANCED COMPOSITE	PERIOD
CURRENT COMPONENTS		
CH-54 Reinf. Fuselage	Boron/Epoxy Strips	MAR 72 - JUL 79 (1)
HLH Rotor Blade	S Glass-Graphite/Epoxy	JUL 76 - AUG 76
AAH Secondary Str.& Blade	Kevlar Woven Cloth & Boron/Epoxy	AUG 76 - DEC 80
UTTAS Tail Rotor	Graphite/Epoxy	OCT 74 - DEC 80
ADV. DEV. COMPONENTS		
Damage Tol. Controls	Chopped-Graphite/Epoxy	(None)
Drive Shaft	Wound-Graphite/Epoxy	OCT 77 - DEC 77
Tubular Spar Rotor Blade	Wound-Kevlar/Epoxy, Graphite Reinf.	SEP 76 - DEC 77
Tail Boom Assy	Wound-Graphite/Epoxy	AUG 75; MAR 77 - JUL 79 (1)
RPV Airframe	Kevlar/Epoxy	DEC 75 - DEC 76
ADV. STRUC. TECH. DEMONSTRATOR		
Supp. Tech. Components	(TBD)	75 - 80
Prototype Vehicle	(TBD)	JAN 80

(1) In-Service Evaluation

DEMONSTRATOR (ASTD)

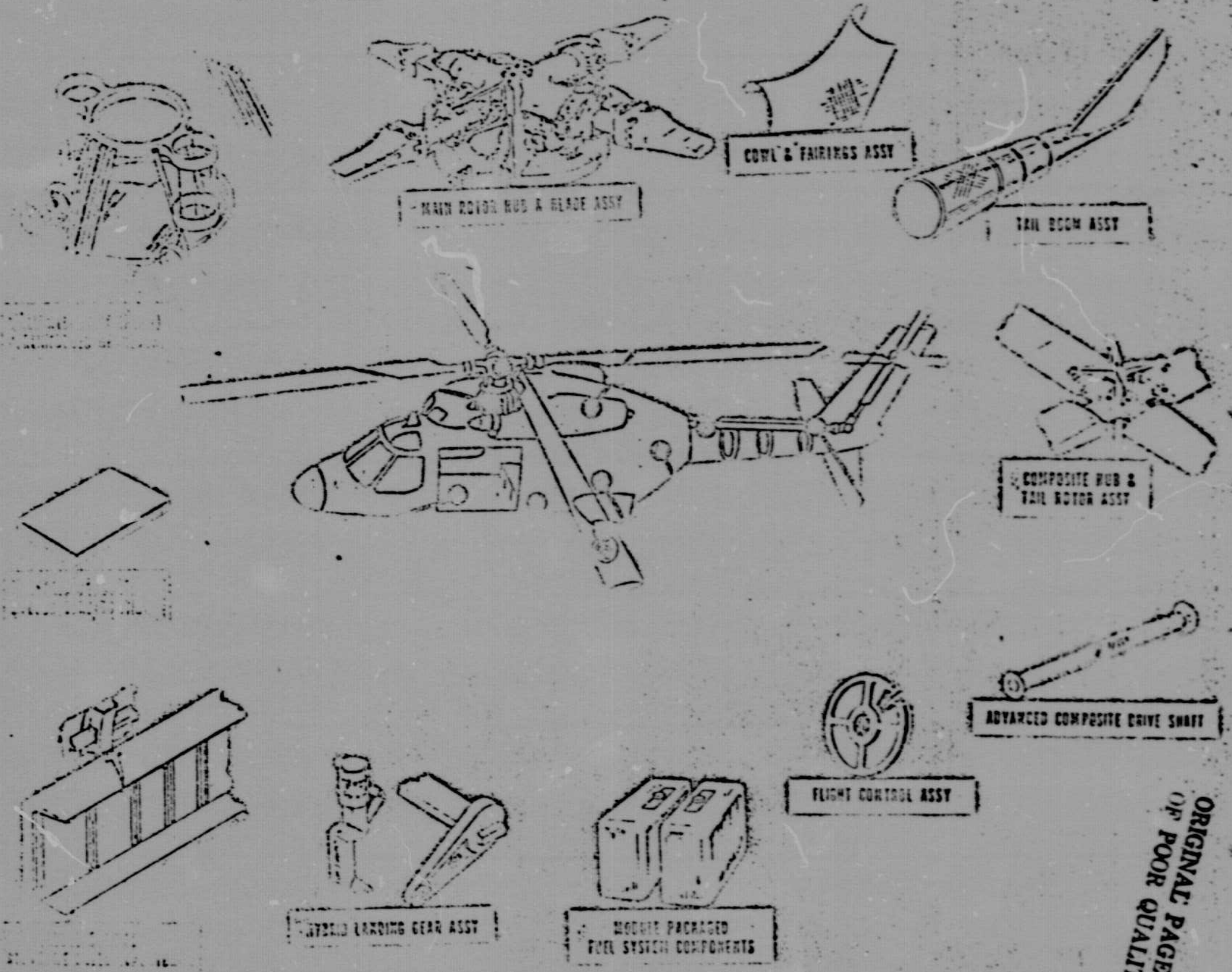


FIGURE 3. APPLICATION OF COMPOSITE MATERIALS TO ARMY EQUIPMENT

AIRCRAFT		
ROTOR BLADES DRIVE SHAFTS TRANSMISSION	ENGINE BEARINGS	CONTROLS FUSELAGE
MISSILES		
ROCKET MOTOR	LAUNCHER	
BRIDGING AND CRAFT		
TRUSSES BEAMS	BOAT HULLS ENGINE	
VEHICLES		
BODY FRAME	DRIVE SHAFTS ENGINE	SUSPENSION SYSTEM
LIGHTWEIGHT WEAPONRY PIPING		
WATER	SEWERAGE	POL DISTRIBUTION
LOGISTICS CONTAINERS		
PROTECTIVE MATERIALS		

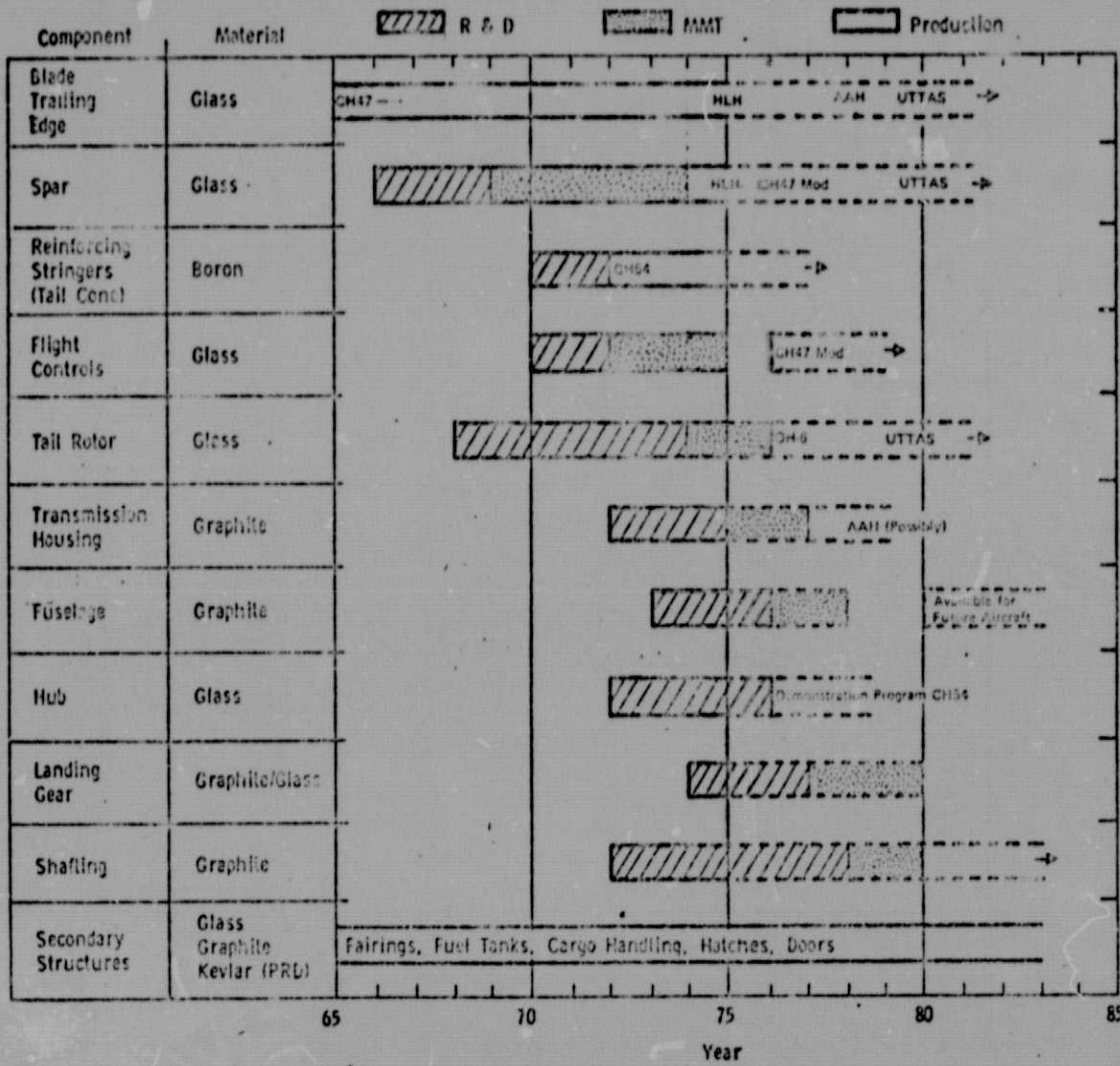
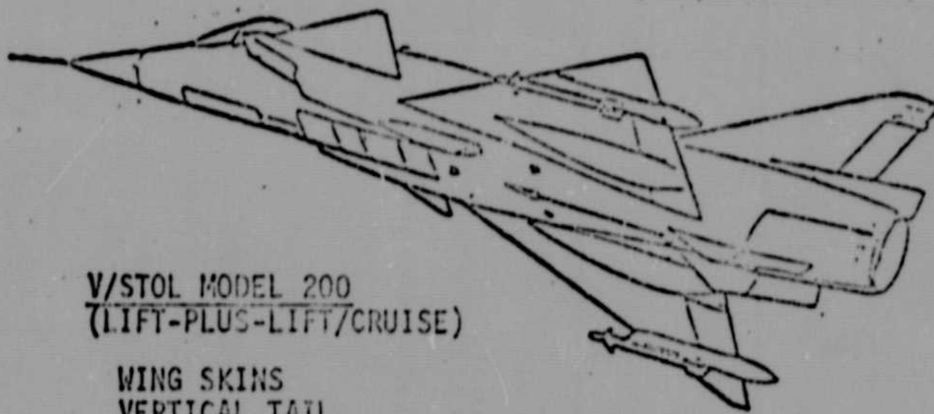


FIGURE 4. USE OF COMPOSITE MATERIALS IN ARMY HELICOPTERS

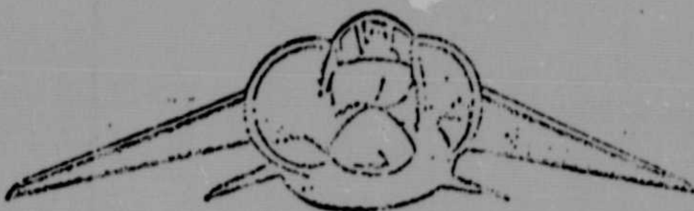
FIGURE 5. NAVY SERVICE EVALUATION OF GRAPHITE COMPOSITE COMPONENTS

COMPONENT	NUMBER OF AIRCRAFT	NUMBER OF COMPONENTS	START FLIGHT EVALUATION
BOM-34E Wing	8	8	AUG 1973
S-3 SPOILER	14	28	MAY 1975
F-4J Access Doors	4	8	DEC 1975
F-14 Landing Gear Door	9	18	MAY 1976
F-14 Overwing Fairing	5	10	MAY 1976
Total	40	72	-



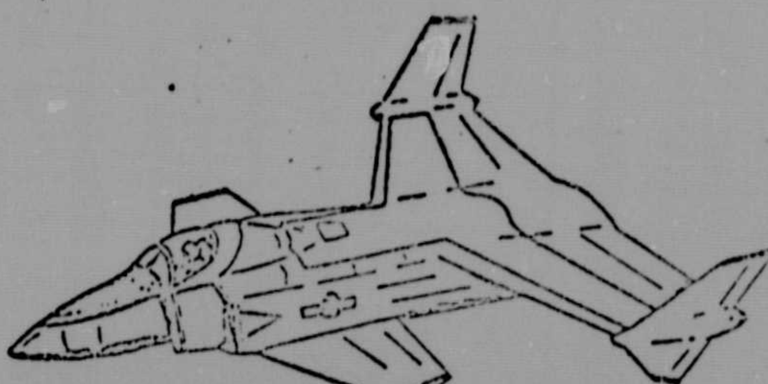
V/STOL MODEL 200
(LIFT-PLUS-LIFT/CRUISE)

WING SKINS
VERTICAL TAIL
CANARD
RUDDER & ELEVON
FUSELAGE SKINS
LG FAIRING & DOORS
ENGINE DUCTS



ADV. HARRIER
(LIFT/CRUISE)

WING SKINS
AILERONS & FLAPS
OVERWING FAIRING
FORWARD FUSELAGE
EMPENNAGE
LANDING GEAR DOORS
ENGINE ACCESS DOORS
WING TIPS



XFV-12A
(AUGMENTER WING)

FIGURE 6. NAVY PRIMARY STRUCTURE DESIGN STUDIES

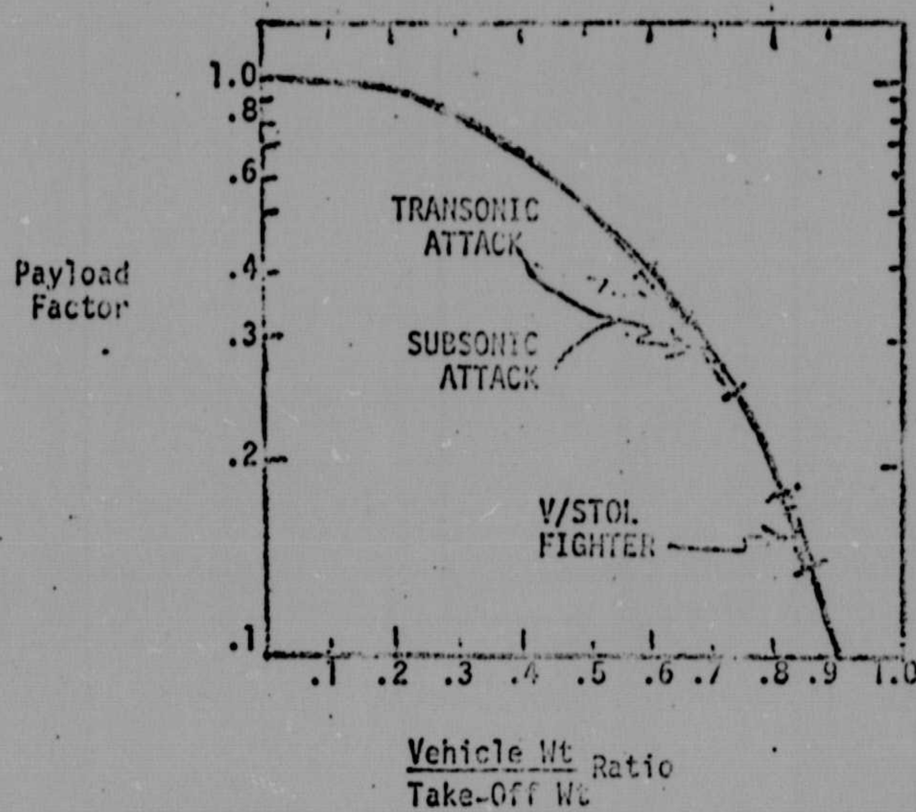


FIGURE 7. PAYLOAD vs VEHICLE WEIGHT

FIGURE 8. NAVY COMPOSITES TECHNOLOGY AREAS OF EMPHASIS

FASTENING AND JOINING

MAINTENANCE AND REPAIR

IMPACT AND BALLISTIC DAMAGE

ENVIRONMENTAL AND CORROSION RESISTANCE

FIRE AND LASER RESISTANCE

HIGHER TEMPERATURE COMPOSITES

COST AND FABRICATION

NDI AND CRITERIA

FRACTURE AND FAILURE CRITERIA

CHARACTERIZATION AND QUALITY CONTROL

FIGURE 9. AIR FORCE ADVANCED COMPOSITES LIMITED PRODUCTION EXPERIENCE

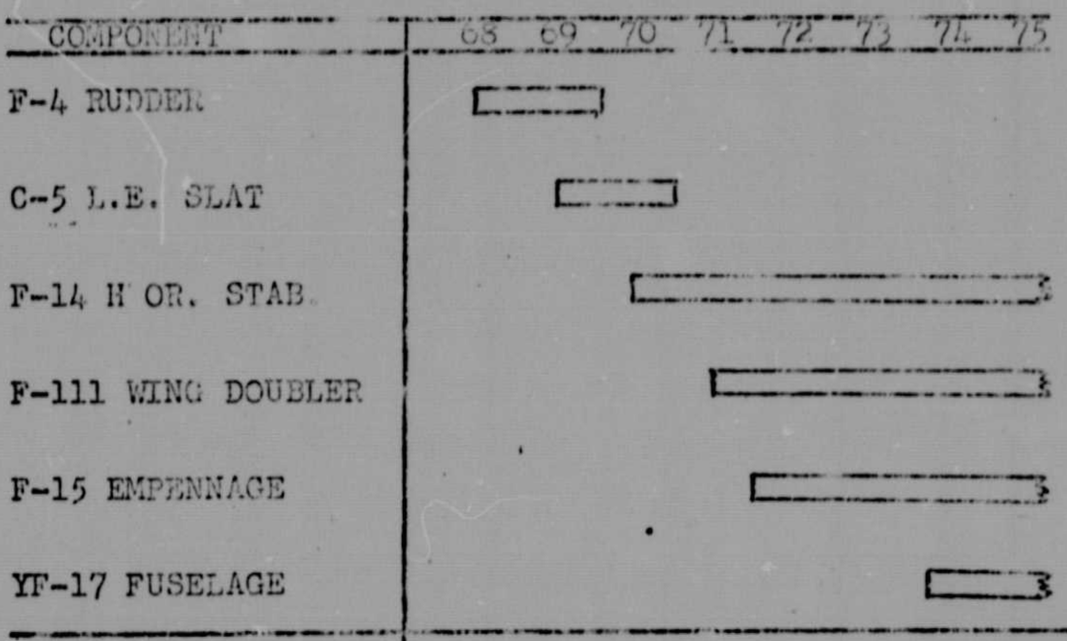


FIGURE 10. AIR FORCE ADVANCED COMPOSITES IN-SERVICE EXPERIENCE

COMPONENT	MATERIAL	NR. IN SERVICE	APPROX. CUMM. FLIGHT HOURS
F-111 WING TRAILING EDGE PANEL	BORON/EPOXY	22	32,050
C-5A LEADING EDGF SLAT	BORON/EPOXY	11	23,450
F-4 RUDDER	BORON/EPOXY	45	51,000
C-141 GEAR POD DOOR	BORON/EPOXY	1	8,800
F-111 UNDERWING FAIRING	GRAPHITE/EPOXY	266	44,700
F-15 EMPENNAGE	BORON/EPOXY	33	5,000

FIGURE 11. ADVANCED COMPOSITE SAVINGS PER ENGINE

ENGINE	POUNDS OF COMPOSITES	ESTIMATED SAVINGS WEIGHT(%)	ESTIMATED SAVINGS COST(%)
TF39	186	37	44
TF34	68	32	31
CF6	280	37	39
F101	41	46	38

FIGURE 12. AIR FORCE ADVANCED COMPOSITE MAJOR THRUSTS

MAJOR THRUST	PAYOFF
REINFORCEMENTS: O HYBRIDS O COMMERCIAL FIBER	O 80-90% COST REDUCTION
RESINS: O LOW TEMPERATURE CURE O ENVIRONMENTAL RESISTANCE	O 50% COST SAVINGS O IMPROVED DURABILITY
MANUFACTURING METHODS: O AUTOMATED TAPE LAYDOWN O SELF-CONTAINED TOOLS O RAPID CURE O RE-USABLE BAG MOLDING O CUTTING/HANDLING TECHNIQUES	O 200-300 LB/HR LAYDOWN RATE O 60% REDUCTION IN FACTORY MANHOURS O LOWER EQUIPMENT FACILITIES INVESTMENT O LOW ENERGY REQUIREMENT

FIGURE 13. AIR FORCE COMPOSITES TECHNOLOGY MILESTONES/GOALS

1970 - 1975	STIFFNESS CRITICAL DESIGN (EMPENNAGE & FAIRINGS) STABLE MATERIALS BASE (LOW/MODERATE TEMPERATURE) COST EFFECTIVE STRUCTURES LIMITED APPLICATION IN MISSILE AND SPACE STRUCTURES (0% - 10% AIRFRAME WEIGHT)
1975 - 1980	STRENGTH CRITICAL DESIGNS (FIGHTER WING) FIGHTER FUSELAGE STRUCTURE GREATER APPLICATION TO MISSILE & SPACE STRUCTURES FLIGHT DEMONSTRATION (REPLACEMENT COMPONENTS) VALIDATION OF LOW COST MANUFACTURING COST PARITY TO 15% COST REDUCTION (10% - 30% AIRFRAME WEIGHT)
1980 - 1990	VOLUME PRODUCTION POTENTIAL (FIGHTER/TRAINER CLASS) ADVANCED VEHICLE STRUCTURAL CONCEPTS DEMONSTRATION OF WARM STRUCTURES CAPABILITY DEMONSTRATION OF LARGE BODY FUSELAGE TECHNOLOGY FULL APPLICATION IN MISSILE & SPACE STRUCTURES COST PARITY TO 20% COST REDUCTION (40% - 65% AIRFRAME WEIGHT)

FIGURE 14. AIR FORCE PRELIMINARY COMPOSITE STRUCTURES ROADMAP

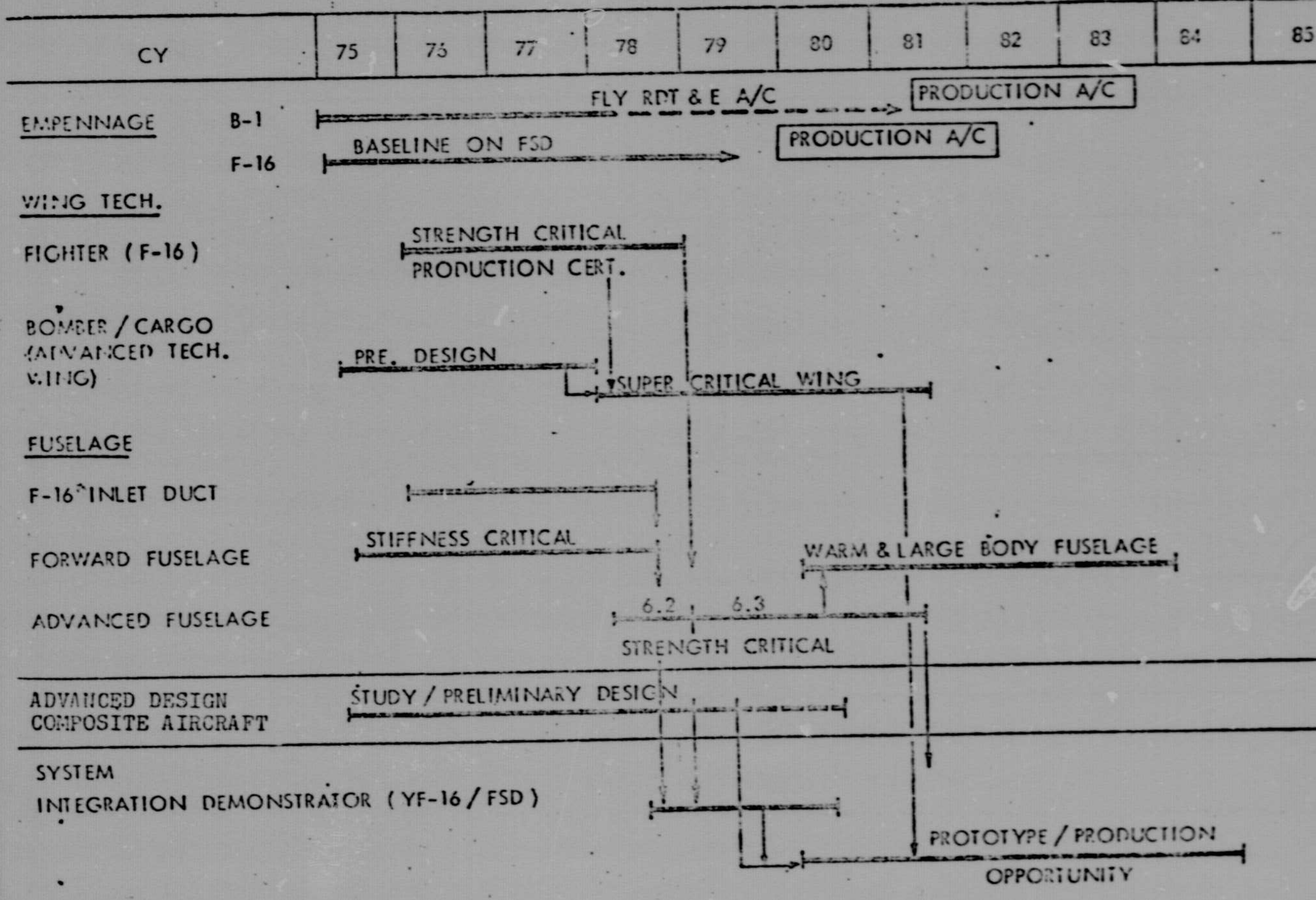
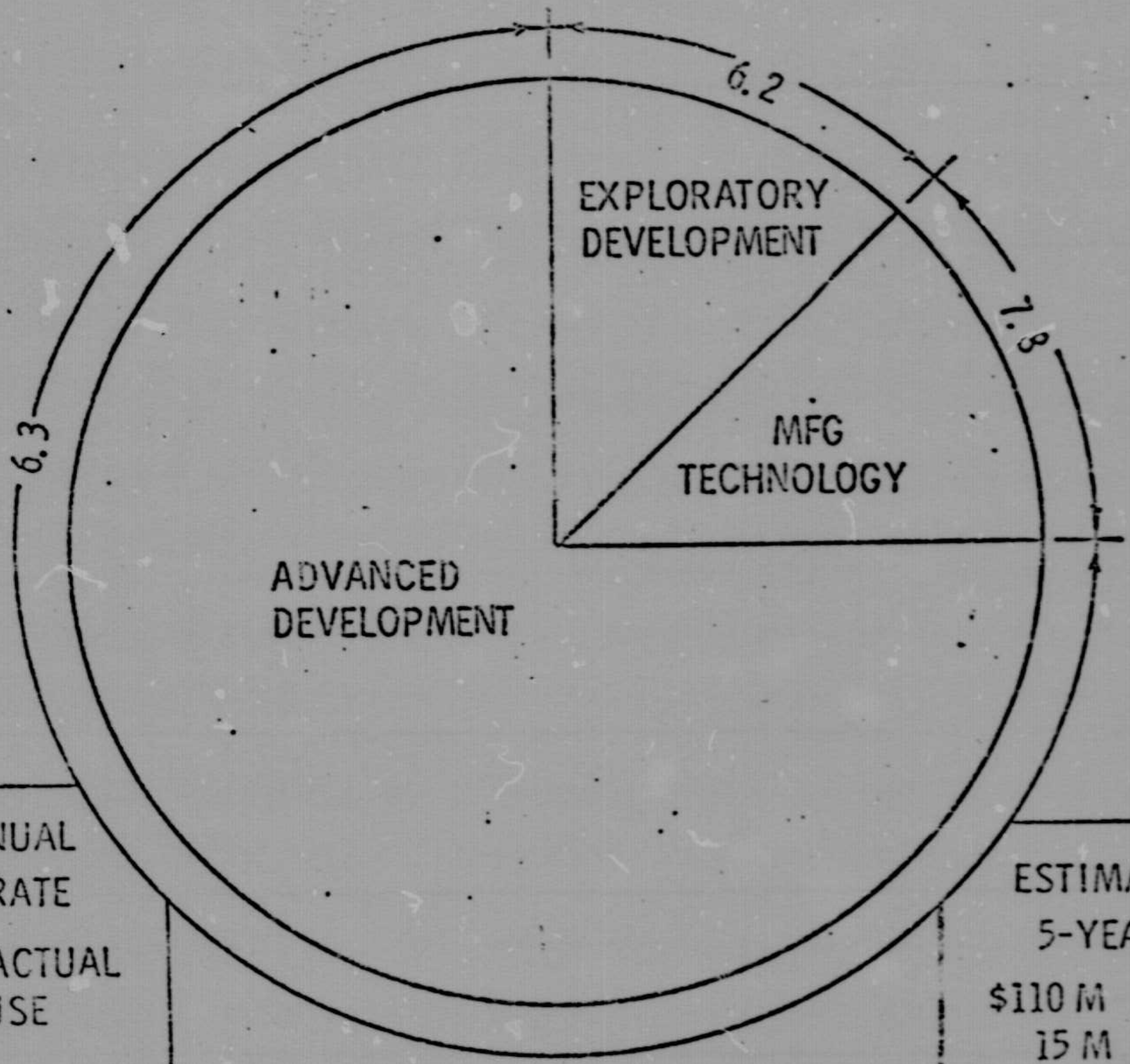


FIGURE 15. THE AIR FORCE COMMITMENT



ESTIMATED ANNUAL INVESTMENT RATE

$22 M CONTRACTUAL
3 M IN-HOUSE
$25 M TOTAL

ESTIMATED 5-YEAR INVESTMENT

$110 M CONTRACTUAL
15 M IN-HOUSE
$125 M TOTAL

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FIGURE 16. NASA COMPOSITES PROGRAM

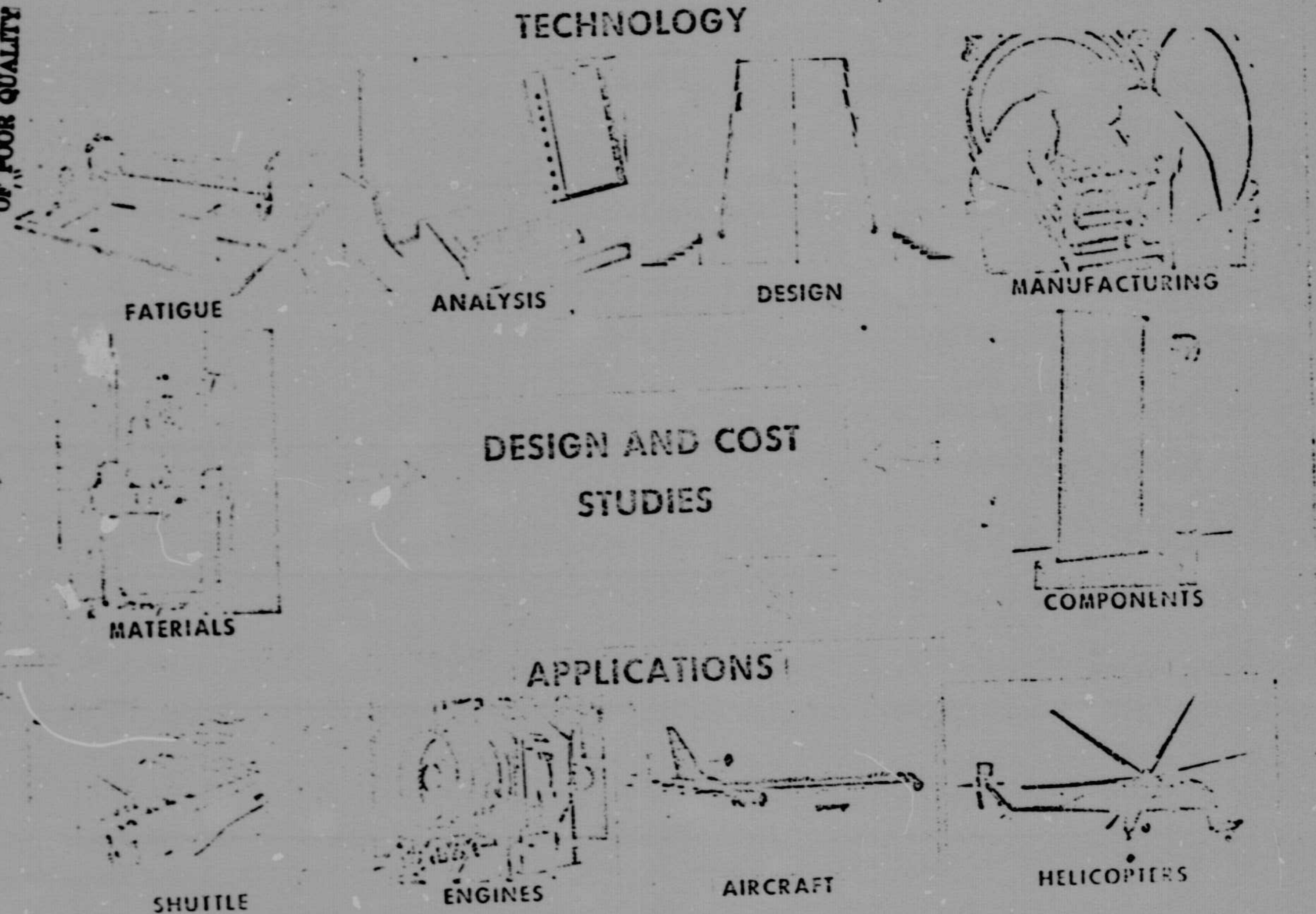


FIGURE 17. NASA SPACE VEHICLE COMPOSITE APPLICATIONS

COMPONENT	MATERIAL	WT. SAVINGS
EXPLORER 49 - Support Booms	Boron/Epoxy	----
PIONEER 10 - Tube Struts	Boron/Epoxy	----
SPACE TELESCOPE - Mirror Support Structure	Graphite/Epoxy	----
SPACE SHUTTLE - Baseline Payload Bay Doors	Graphite/Epoxy	1070 LB
Ti Aft Thrust Structure	Boron/Epoxy Reinf.	900 LB
Purge & Vent Lines	Kevlar/Epoxy	200 LB
Mid-Fuselage Frame Tubes	Boron/Aluminum	180 LB
Orbital Maneuvering Pods	Graphite/Epoxy	300 LB
Pressure Vessel Overwrap	Kevlar/Epoxy	435 LB

FIGURE 18. NASA IMPACT IMPROVEMENT PROGRAM
TF39 COMPOSITE FAN BLADE

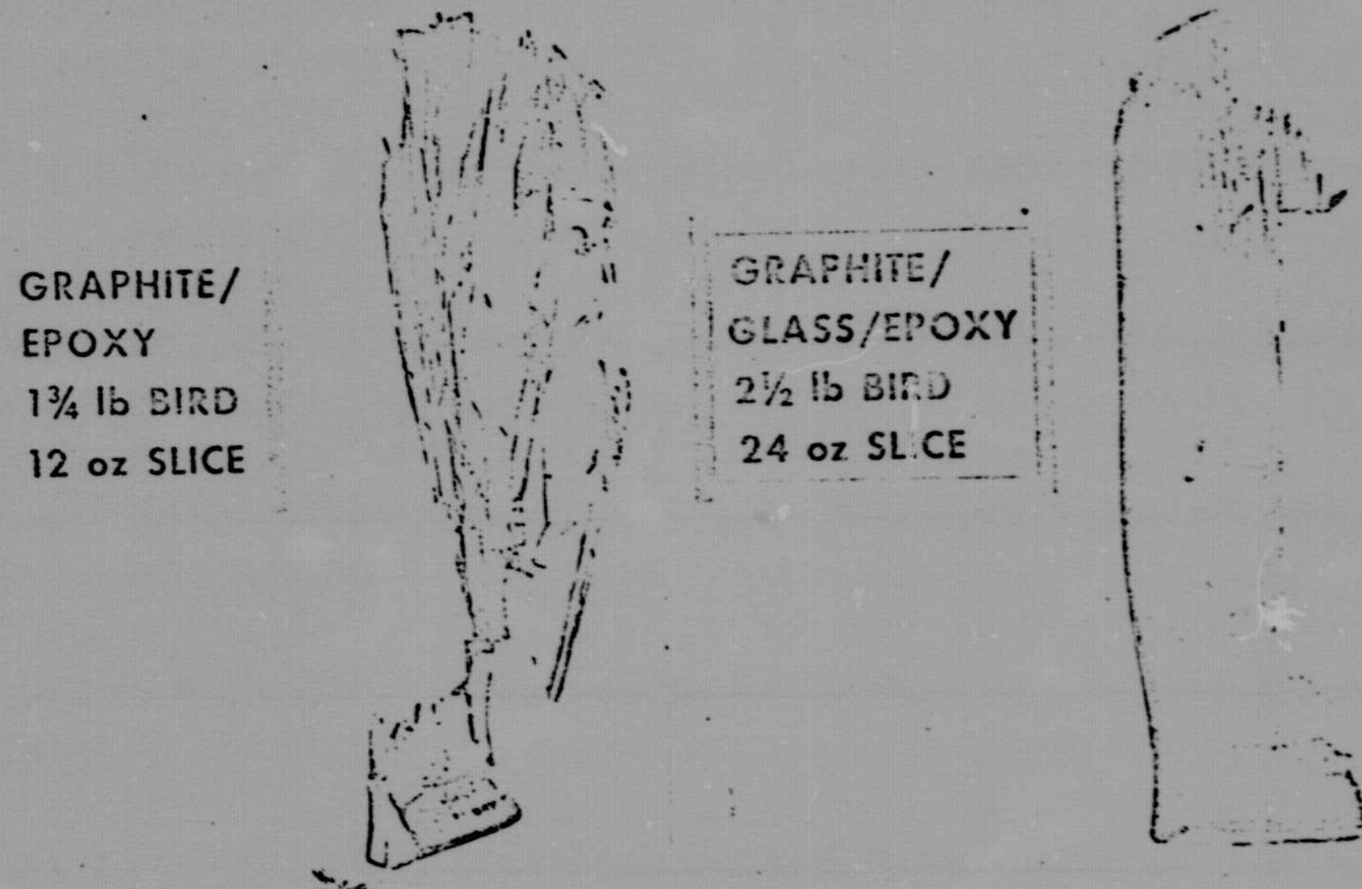


FIGURE 19. NASA FLIGHT SERVICE SUMMARY

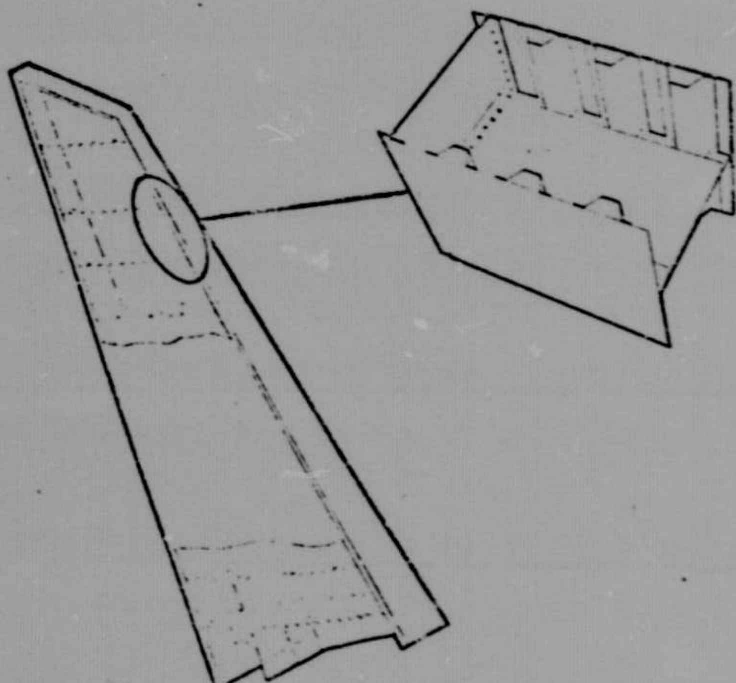
A/C AND COMP. % AND PRINCIPAL COMPOSITE	START OF FLIGHT SERVICE	NUMBER PARTICIPATING		CUMULATIVE FLIGHT HOURS			
				JUNE 1, 1975		DECEMBER 31, 1981	
		A/C	COMP	HIGH TIME A/C	TOTAL COMP	HIGH TIME A/C	TOTAL COMP
CH-54B TAIL CONE 8% BORON/EPOXY (REINF.)	MARCH 1972	1	1	527	527	1000	1000
L-1011 FAIRING PANELS 100% KEVLAR 49/EPOXY	JANUARY 1973	3	18	6293	88 916	23 410	353 800
B-737 SPOILERS 35% GRAPHITE/EPOXY	JULY 1973	27	120	4118	358 000	19 734	1 938 000
C-130 CENTER WING BOX 8% BORON/EPOXY (REINF.)	OCTOBER 1974	2	2	436	781	5176	10 260
DC-10 AFT PYLON SKIN 100% BORON/ALUMINUM	AUGUST 1975	3	3			19 750	59 250
DC-10 UPPER AFT RUDDER 77% GRAPHITE/EPOXY	JUNE 1976	10	10			16 300	155 000
L-1011 VERTICAL FIN 83% GRAPHITE/EPOXY	JANUARY 1979	2	2			8750	17 000
TOTALS		48	156	11 374	448 224	94 120	2 534 310

FIGURE 20. L-1011 VERTICAL·FIN

FLIGHT SERVICE DATA

AIRCRAFT	COMPONENTS	AIRLINE
1	1	TWA
1	1	EASTERN

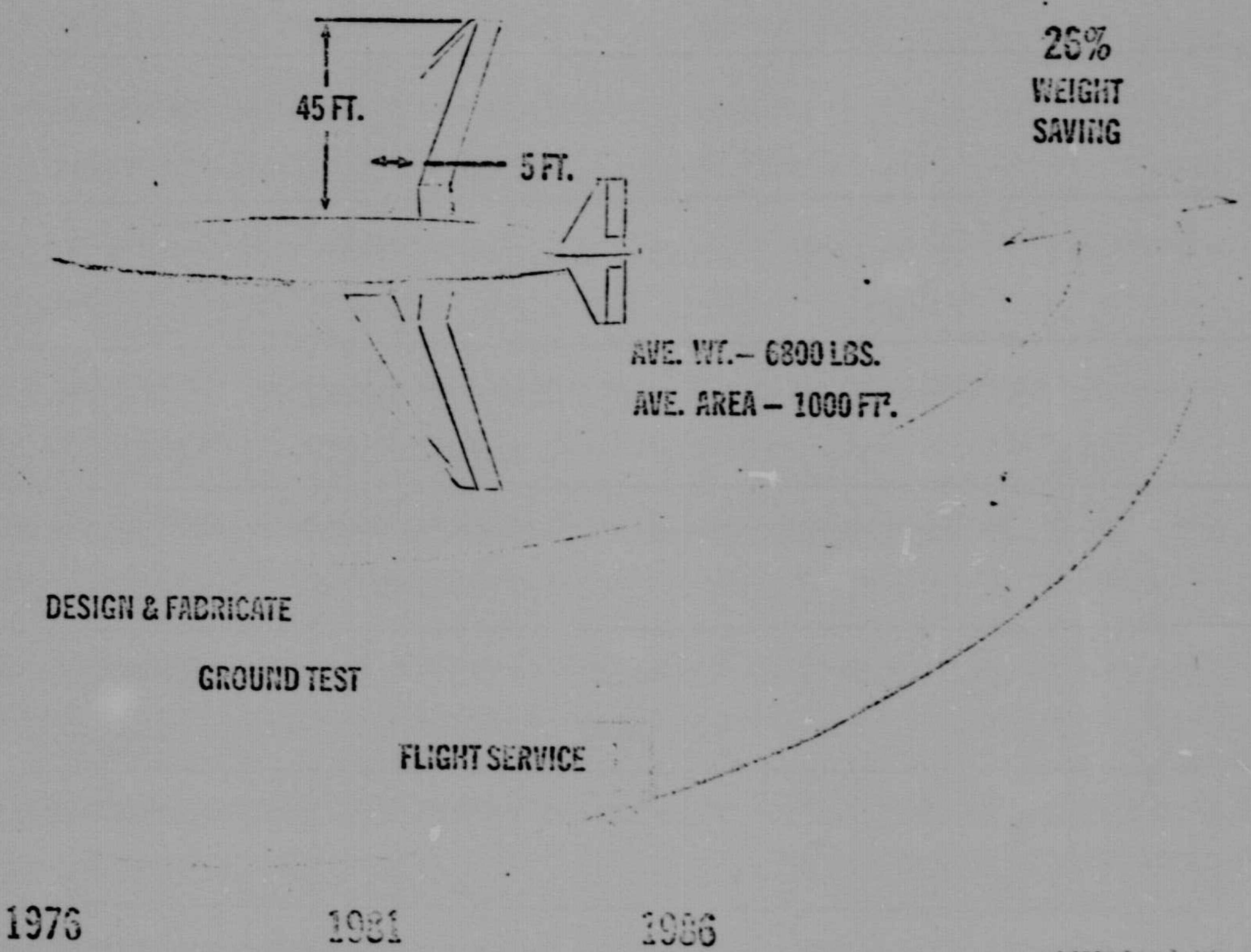
TO BE INITIATED JANUARY 1979



COMPONENT DATA

9x25 ft, 150 sq ft
GRAPHITE/KEVLAR/EPOXY
640 lb 83% COMPOSITE
25% WEIGHT SAVED
1 PER AIRCRAFT

FIGURE 21. NASA COMPOSITE WING PROGRAM



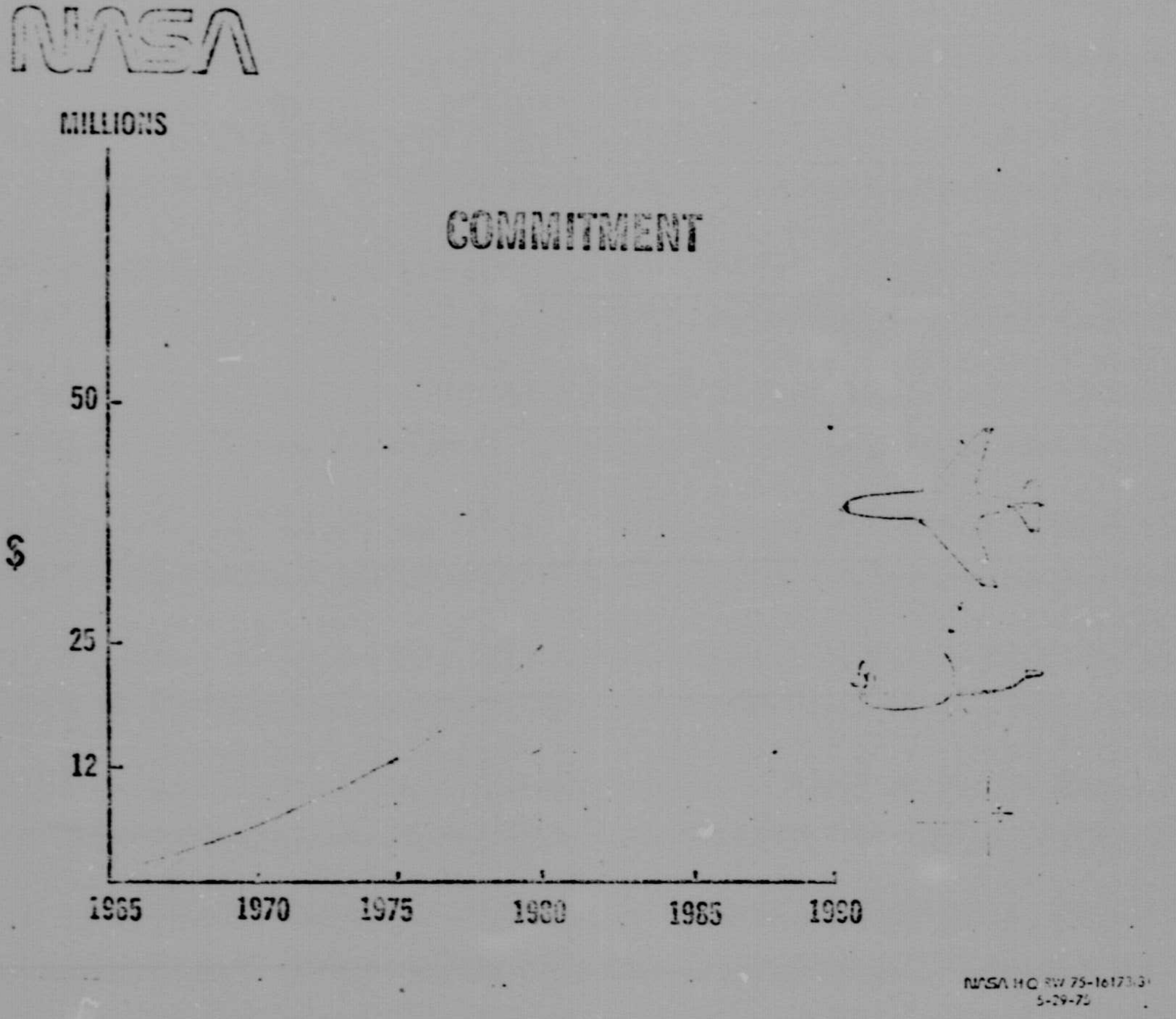


FIGURE 22. NASA COMMITMENT TO ADVANCED COMPOSITES TECHNOLOGY